ASEAN FEDERATION OF GLASS MANUFACTURERS
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All-electric melting prospects for glass container production

Lars Biennek discusses the opportunities and limitations of all-electric melting furnaces for glass container production, as the industry searches for CO_2-free melting solutions.

Currently, the world is under pressure to limit global warming. Whether climate change is due to human interference or not is an outdated discussion. Society has to change its way of life and the way to produce goods. The boom in the glass industry shows that glass meets consumer needs for a sustainable packaging material, much in contrast to plastic. The entire industry is forced to produce goods more efficiently and with less CO_2 emission.

As a leading supplier of innovative glass melting furnaces and complete production lines, HORN is continuously developing and suppling eco-friendly solutions for the glass industry. An economic motivator for glass producers worldwide is the increase of CO_2 allowances. The shortage of fossil fuels in the near future and stricter industrial emission directives for NO_x and SO_x emissions should also be mentioned.

The use of electrical power seems to be a solution for the dramatic reduction of CO_2 emissions, at least on glass factory sites. When electrical power is produced by wind, solar, water or other regenerative energy sources, CO_2 emissions can be reduced generally. Furthermore, nuclear power is still making a significant contribution to reducing CO_2 emissions.

Energy producers and energy suppliers share a responsibility to deliver electrical power that is environmentally-friendly and is available 24/7. As a reputable German engineering company, HORN assumes full responsibility. The evidence lies in the intensive efforts of the R&D Department in the development of large all-electric furnaces, hybrid furnaces and the further improvement of the efficiency and reduction of emissions of conventional furnaces. For example, every year the company supplies 15-20 large electric boosting systems for container and float glass furnaces, with an upwards trend in number of installations and size of installed electric power.

Future trends

Future trends for the glass container sector are still unclear. Increasingly, fossil fuel-based furnaces are boosted electrically. Oxy fuel furnaces have been developed and partially introduced but this does not seem to be the solution. In addition, hybrid furnaces are under development throughout the world.

An end-fired furnace with electric boosting is already a hybrid furnace, because two heating technologies are combined, hence it is a so-called electrically boosted furnace. The understanding of the hybrid furnace nowadays is rather the technological solution, where the electric heating of the furnaces dominates and is only supported by natural gas heating. If in this type of furnace the natural gas heating is stopped completely, it would end up in an all-electric furnace based on hot top technology. But what about the all-electric furnace based on cold top technology (AEF)? Is there a chance for this solution in the future?

The all-electric furnace based on cold top technology has been successfully applied for many decades. Its use has been driven either by non-existing gas pipelines, too high fossil fuel prices or by emission issues, especially in connection with the production of technical glass, where the volatilisation of boron, chlorine and fluorine volatiles occur, partially connected with glass defects. The typical melting capacity for specialty glass is < 30 tonnes/day; for container glass it is <80 tonnes/day; and for fibre glass, it is < 200 tonnes/day, of course with exceptions in each case for higher and lower melting capacities. The largest all-electric furnace in operation worldwide is located in Western Europe, with an impressive total melting capacity of 400 tonnes/day for fibre glass.

The all-electric melting process following the cold top technology route is basically a vertical melting process. A batch layer uniformly covers the entire glass bath. The batch is continuously introduced into the furnace at the top side of the batch layer. The subsequent melting process takes place from the top side of the batch layer until the bottom of the furnace. At the end, the melt leaves the furnace through its ▸

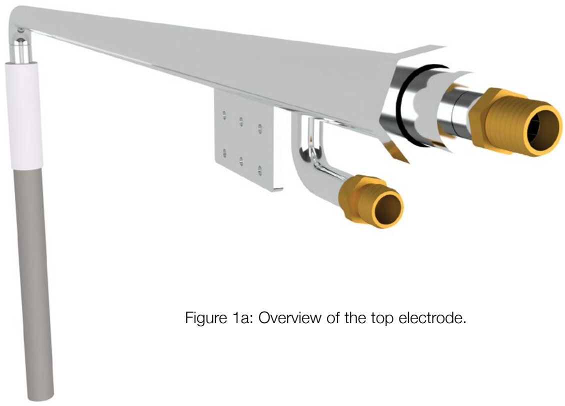

Figure 1a: Overview of the top electrode.

Lars Biennek (second from left), with AFGM dignitaries at the 43rd AFGM Glass Conference in Cebu.

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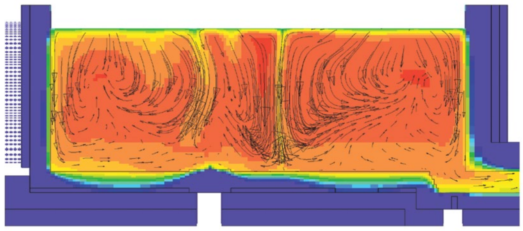
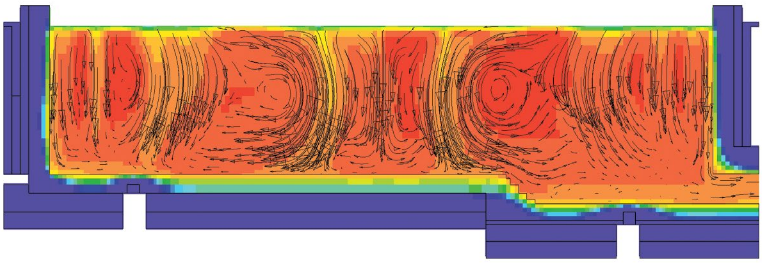
Figure 1b: All-electric furnace with top electrodes.

Figure 2: Comparison of the convection pattern between a 60 tonnes/day (20m^2)dodecagonal furnace (top) and a 140 tonnes/day (50m^2) dodecagonal furnace (bottom). The 140 tonnes/ day furnace shows unstable convection pattern and critical downstream in the centre.





throat, which is also located at the bottom side.

A very important basic requirement is to produce and maintain a uniform and thermal insulating batch layer at the top of the glass bath. Only a sufficient thermal insulation makes it possible to keep the melting and the refining temperature above the level needed. In this way, the temperature of the superstructure can be kept at a temperature of 100-180°C, which is necessary for safe operation of the batch charger. The batch layer thickness increases proportionally to the melting capacity and vice versa. This technological connection also leads to the limits of this melting process.

Batch layer condition

The condition of the batch layer depends on the area-specific melting capacity and can be described as follows: The lower the melting capacity, the lower the batch layer thickness. This means the lower the batch layer thickness, the lower the thermal insulation. At a certain level, the minimum necessary temperature in the melt cannot be maintained due to excess thermal losses through the batch layer.

A further increase of the electric heating power will melt down the batch layer even faster and will not compensate the thermal losses, as some might expect. A further drop of the temperature is an unavoidable result of the power increase. On the other side, the higher the melting capacity, the thicker the batch layer. This means fewer thermal losses. The thermal insulation of the batch is increasing but at the same time, its permeability for gases is decreasing. Now, at a certain point, gases from the batch reactions cannot penetrate the batch layer fast enough. The melt below the batch layer can no longer exhaust. An accumulation of gases between the batch layer and the melt is the consequence. As a result, heat transfer from the melt to the batch, which keeps the melting process running, is no longer ensured.

Ultimately, the area-specific melting rate will drop dramatically and the batch layer needs to come back to the target condition at a lower melting capacity. Raw materials selection (including cullet) has a significant influence on the melting speed and the permeability for gases as well. It is now understandable why the flexibility of the melting capacity (70%-100%), the share of cullet (30%-60%) and the selection of suitable raw materials are limited. These technological aspects define the disadvantages of the cold top electric furnace.

Cullet

Cullet usage in the glass melting process is a popular way for saving raw materials and for reducing energy consumption. Unfortunately, there is always a potential risk of metallic contaminations in recycled cullet, especially post-consumer recycled glass introduced in the furnace.

Three-phase convection (metallic melt – glass melt – refractory) is the driving process for pitting corrosion, which in the worst case leads to a complete uncontrolled furnace drain. If bottom electrodes are applied, either the pitting corrosion is intensified due to the higher bottom temperature level or a direct interaction of the metallic melt with the electrode occurs. Both processes are increasing the risk of an uncontrolled furnace leakage. On the other hand, side electrodes could solve the interaction issue but a typical high load of the electrodes in electric furnaces connected with the driven intensive convection of the melt will increase the corrosion of the sidewall significantly. A short furnace lifetime would be the result.

Electrode placement

The use of top electrodes seems to be the way out. Top electrodes (as shown in figure 1a) are characterised by a vertical molybdenum electrode, which is connected to a horizontal water-cooled connector. This, in turn, is attached to a swing-in device.

The vertical molybdenum electrode penetrates the batch layer, which has a typical thickness of 25cm-3cm. The upper part of the electrode remaining in the batch layer is internally water-cooled. In this way, oxidation of the molybdenum is suppressed and the batch layer above the hot spot of the electrode is locally and thermally stabilised.

The above-mentioned interaction with metallic contaminations from recycled cullet can be excluded. Sidewall corrosion is moderate and an easy exchange of worn electrodes are the main advantages of top electrodes. A HORN all-electric furnace using top electrodes can be seen in figure 1b.

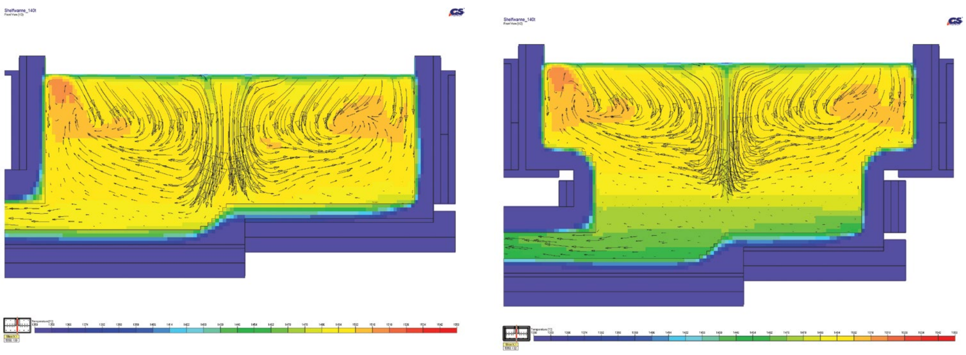


Figure 3: Comparison of the convection pattern between a 140 tonnes/day (20m^2) rectangular furnace (left) and a 140 tonnes/day (20m^2) rectangular furnace with a shelf (right).

CFD modelling

During the development of larger all-electric furnaces, a variety of electrode positions were tested in CFD models and evaluated. The most compromising results were gathered with the application of top electrodes. These results will be described and evaluated below. ▸

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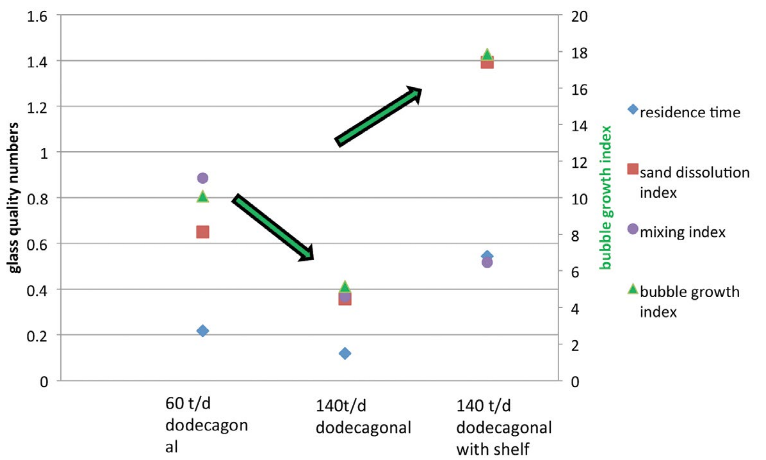

Figure 4: Glass quality indicators for dodecagonal furnaces with a melting capacity of 60 tonnes/day (20m^2) and dodecagonal furnaces with a melting capacity of 140 tonnes/day (20m^2, with a shelf and without a shelf).

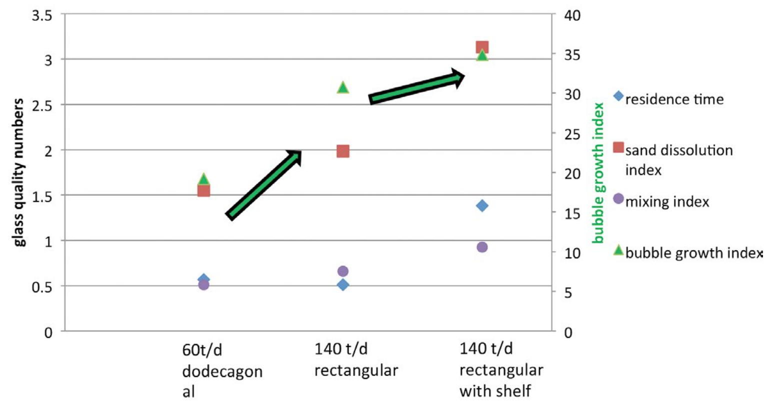

Figure 5: Glass quality indicators for a dodecagonal furnace with a melting capacity of 60 tonnes/day (20m^2) and rectangular furnaces with a melting capacity of 140 tonnes/day (50m^2, with shelf and without shelf).

The basis for the evaluation of different cases based on CFD modelling is an existing dodecagonal furnace for super flint glass with a melting area of 20m^2 and a melting capacity of 60 tonnes/day, heated by means of top electrodes. The glass quality reached is <10 seeds/100g. The modelling work compares two main furnace designs to investigate their suitability for the production of extra flint glass with a melting capacity of 140 tonnes/day. The evaluation for green and amber glass has to be investigated and evaluated separately, because their thermal transparency is different and this would influence convection in the furnace significantly.

The first sequence of modelling cases follows the dodecagonal furnace shape. The second sequence follows the rectangular shape. In the case of the dodecagonal furnace, the electrode distance will increase by increasing the melting surface.

In comparison to the dodecagonal shape, the rectangular furnace bears the chance to keep the distance of the top electrodes constant, independently of the melting surface (of course only in certain limits is this technologically reasonable). The same distance of the top electrodes avoids a lack of energy between the electrodes for keeping the same good conditions for the melting processes.

Both furnaces are heated by 24 top electrodes in total. The electric heating circuits of the rectangular furnace are separated into three heating zones (left, centre and right). Each heating zone is heated by means of 4x2 top electrodes in a Scott connection. The dodecagonal furnace is heated by means of the top electrodes in three-phase connection. Each phase uses 2x4 top electrodes. Both furnace types have a melting area of 50m^2. The rectangular furnace is 10m wide and 5m deep. The dodecagonal furnace has a diameter of 7.9m. The total required electric power is about 6000 kW for 30% cullet for a new furnace.

For comparison and evaluation of the results of the modelling cases, the following typical indicators are used:

- Minimum residence time.
- Sand dissolution index.
- Mixing index.
- Bubble growth index.

The comparison of the convection pattern of a 60 tonnes/day dodecagonal furnace and a 140 tonnes/day dodecagonal furnace is shown in figure 2. The convection in the centre of the 60 tonnes/day furnace is moderate. Due to the increased distance of the electrodes at the 140 tonnes/day furnace, the lack of energy in the centre drives a very intensive downstream convection.

The glass quality indicators in figure 4 show a drop of all numbers. A significant decrease of glass quality is to be expected. Only the additional implementation of a shelf can partially compensate the weakness of this design (convection pattern is not shown here, see glass quality indicators in figure 4). It becomes obvious that the shape of the dodecagonal furnace in general will not be the proper design for larger melting capacities.

The convection pattern of a rectangular furnace without shelf, compared to a rectangular furnace with a shelf is shown in figure 3. Both types of furnaces show even better convection flow compared to the proven dodecagonal 60 tonnes/day furnace. The shelf additionally generates a well-defined conditioning zone, which lowers the entrance temperatures into the throat. This means both lower throat corrosion and lower entrance temperatures at the distributor entrance.

The glass quality indicators shown in figure 5 are increasing significantly, especially with the implementation of a shelf. The comparison of the glass quality numbers of the 140 tonnes/day rectangular furnace with the 140 tonnes/day dodecagonal furnace confirms very clearly the advantage of the rectangular furnace with top electrodes for larger melting capacities.

With its rectangular design and a capacity of 140 tonnes/day (figure 6), the HORN all-electric furnace is an excellent solution for melting flint and super flint glass. Thanks to the use of top electrodes, it is the most reasonable and safest solution for melting container glass with respect to glass quality, stability of the melting process, safe operation (metallic contamination) and furnace lifetime. The limited flexibility of the melting capacity, as well as the limited share of cullet, are the typical main disadvantages of all-electric furnaces based on cold top technology. This type of furnace gives customers the opportunity to reduce CO_2 emissions radically. Unfortunately, the necessary uninterrupted supply of CO_2-free electrical energy at an economically accessible level is still not available in most countries.

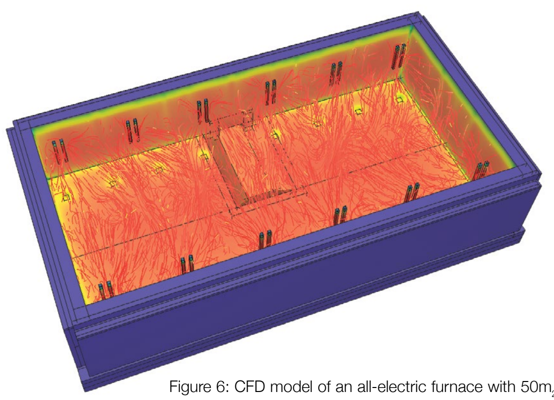

Figure 6: CFD model of an all-electric furnace with 50m$_2$ and a melting capacity of 140 tonnes/day for high quality super flint glass, showing the convection pattern for the melt below the batch layer.

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